

00-SM6-262

TITLE: **DECABORANE VAPORIZER HAVING
IMPROVED VAPOR FLOW**

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"Express Mail" Mailing Label No. EK762674545US
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Related Patents and Patent Applications

[0001] The following U.S. patent and patent application are incorporated by reference herein as if they had been fully set forth: U.S. Patent No. 6,107,634, filed April 30, 1998, entitled "Decaborane Vaporizer"; and U.S. Patent Application Serial Number: 09/416,159, filed October 11, 1999, entitled "Decaborane Ion Source".

Field of the Invention

[0002] The present invention relates generally to ion sources for ion implantation equipment and more specifically to a decaborane vaporizer for an ion source having improved vapor flow characteristics.

Background of the Invention

[0003] Ion implantation has become a standard accepted technology of industry to dope workpieces such as silicon wafers or glass substrates with impurities in the large scale manufacture of items such as integrated circuits and flat panel displays. Conventional ion implantation systems include an ion source that ionizes a desired dopant element which is then accelerated to form an ion beam of prescribed energy. The ion beam is directed at the surface of the workpiece to implant the workpiece with the dopant element. The energetic ions of the ion beam penetrate the surface of the workpiece so that they are embedded into the crystalline lattice of the workpiece material to form a region of desired conductivity.

[0004] The implantation process is typically performed in a high vacuum process chamber which prevents dispersion of the ion beam by collisions with residual gas molecules and which minimizes the risk of contamination of the workpiece by airborne particulates.

[0005] Ion dose and energy are the two most important variables used to define an implant step. Ion dose relates to the concentration of implanted ions for a given semiconductor material. Typically, high current implanters (generally greater than 10 milliamps (mA) ion beam current) are used for high dose implants, while medium current implanters (generally capable up to about 1 mA beam current) are used for lower dose applications. Ion energy is used to control junction depth in semiconductor devices. The energy levels of the ions that make up the ion beam determine the degree of depth of the implanted ions. High energy processes such as those used to form retrograde wells in semiconductor devices require implants of up to a few million electron volts (MeV), while shallow junctions may only demand energies below 1 thousand electron volts (KeV).

[0006] The continuing trend to smaller and smaller semiconductor devices requires implanters with ion sources that serve to deliver high beam currents at low energies. The high beam current provides the necessary dosage levels, while the low energy levels permit shallow implants. Source/drain junctions in complementary metal-oxide-semiconductor (CMOS) devices, for example, require such a high current, low energy application.

[0007] A typical ion source 10 for obtaining atoms for ionization from a solid form is shown in Figure 1. The ion source comprises a pair of vaporizers 12 and 14 and an ionization chamber 16. Each of the vaporizers is provided with a crucible 18 in which a solid element or compound is placed and which is heated by a heater coil 20 to vaporize the solid source material. Heater coil leads 22 conduct electrical current to the heater coils and thermocouples 24 provide a temperature feedback mechanism. Air cooling conduit 26 and water-cooling conduit 28 is also provided.

[0008] Vaporized source material passes through a nozzle 30, which is secured to the crucible 18 by a graphite nozzle retainer 32, and through vaporizer inlets 34 to the interior of the ionization chamber 16. Alternatively, compressed gas may be fed directly into the ionization chamber by means of a gas inlet 36 via a gas line 38. In either case, the gaseous/vaporized source material is ionized by an arc

chamber filament 40 that is heated to thermionically emit electrons.

[0009] Conventional ion sources utilize an ionizable dopant gas which is obtained either directly from a source of a compressed gas or indirectly from a solid from which has been vaporized. Typical source elements are boron (B), phosphorous (P), gallium (Ga), indium (In), antimony (Sb), and arsenic (As). Most of these source elements are provided in solid form, except boron, which is typically provided in gaseous form, e.g., as boron trifluoride (BF_3).

[0010] In the case of implanting boron trifluoride, a plasma is created which includes singly charged boron (B^+) ions. Creating and implanting a sufficiently high dose of boron into a substrate is usually not problematic if the energy level of the beam is not a factor. In low energy applications, however, the beam of boron ions will suffer from a condition known as "beam blow-up", which refers to the tendency for like-charged ions within the ion beam to mutually repel each other. Such mutual repulsion causes the ion beam to expand in diameter during transport, resulting in vignetting of the beam by multiple apertures in the beamline. This severely reduces beam transmission as beam energy is reduced.

[0011] Decaborane ($\text{B}_{10}\text{H}_{14}$) is a compound which has not heretofore been used as a significant source of boron for boron implants. The vaporization of decaborane cannot be suitably controlled in the crucible of the ion source of Figure 1 because decaborane in the solid state has a melting point of about 100°C . Heat generated within the arc chamber 16 will cause the crucible to achieve such a temperature even if the vaporizer heaters are not energized, because the proximity of the solid phase material to the arc chamber results in radiative heating of the material. (The vaporization of phosphorous, on the other hand, can be accurately controlled in the crucible of the ion source of Figure 1 because it has a melting point of about 400°C .) This prevents the establishment of a moderate temperature (less than 200°C) thermal equilibrium within the local environment of the source material.

[0012] Decaborane, however, is an excellent source of feed material for boron implants because each decaborane molecule ($\text{B}_{10}\text{H}_{14}$) when vaporized and

ionized can provide a molecular ion comprised of ten boron atoms. Such a source is especially suitable for high dose/low energy implant processes used to create shallow junctions, because a molecular decaborane ion beam can implant ten times the boron dose per unit of current as can a monotomic boron ion beam. In addition, because the decaborane molecule breaks up into individual boron atoms of roughly one-tenth the original beam energy at the workpiece surface, the beam can be transported at ten times the energy of a dose-equivalent monotomic boron ion beam. This feature enables the molecular ion beam to avoid the transmission losses that are typically brought about by low energy ion beam transport.

[0013] Another important requirement of solid source vaporizers is that the vapor flow output (to nozzle 30 in Figure 1) remain constant so that the ionization chamber receives a consistent source of vaporized material to ionize. For example, variations in the temperature of the vaporizer load may result in a decreased gas flow from the vaporizer to the ionization chamber, and a subsequent reduction in ionizer yield.

[0014] Accordingly, it is an object of the present invention to provide an ion source for an ion implanter which can accurately and controllably vaporize decaborane, or other suitable implant material, to overcome the deficiencies of known ion sources. It is a further object of the present invention to provide an ion source having a vaporizer that provides a stable and consistent vapor flow output.

Summary of the Invention

[0015] An ion source for an ion implanter is provided, comprising: (i) a sublimator having a cavity for receiving a source material to be sublimated and for sublimating the source material; (ii) a gas injector for injecting gas into the cavity; (iii) an ionization chamber for ionizing the sublimated source material, the ionization chamber being located remotely from the sublimator; and (iv) a feed tube for connecting the sublimator to the ionization chamber. The gas injected into the cavity may be either helium or hydrogen, and is designed to improve the heat

transferability between walls of the sublimator and the source material.

Brief Description of the Drawings

[0016] Figure 1 is a perspective, partially cross sectional view of a conventional ion source for an ion implanter;

[0017] Figure 2 is a schematic, partially cross sectional view of a first embodiment of an ion source for an ion implanter constructed according to the principles of the present invention; and

[0018] Figure 3 is a graphical representation of the decaborane vapor partial pressure in the ion source of Figure 2, shown both incorporating the co-gas injection mechanism of the present invention, and without.

Detailed Description of a Preferred Embodiment of the Invention

[0019] Referring now to Figure 2 of the drawings, a first embodiment of an ion implanter ion source 50 which has been constructed according to the present invention is shown. The ion source 50 comprises a non-reactive, thermally conductive sublimator or crucible 52, a heating medium reservoir 54, a heating medium pump 55, a temperature controller 56, an ionization chamber 58, and a mass flow controller 60. The crucible 52 is located remotely from the ionization chamber 58 and connected thereto by a feed tube 62, constructed of quartz or stainless steel. The feed tube 62 is surrounded by an outer single-chamber annular sheath 90 along substantially the entire length thereof.

[0020] The crucible 52 provides a walled container 64 enclosing a cavity 66 for containing a source material 68. The container is preferably made of a suitable non-reactive (inert) material such as stainless steel, graphite, quartz or boron nitride and which is capable of holding a sufficient amount of source material such as decaborane ($B_{10}H_{14}$). Although the invention is described further below only in terms of decaborane, it is contemplated that the principles

of the present invention may be used for other molecular solid source materials, such as indium chloride (InCl), which are characterized as having both low melting points (*i.e.*, sublimation temperatures of between 20° C and 150° C) and significant vapor pressures (*i.e.*, between 10^{-2} Torr and 10^3 Torr).

[0021] The decaborane is vaporized through a process of sublimation by heating the walls of the walled container 64 with a heating medium 70 contained in reservoir 54. The process of sublimation comprises the transformation of the decaborane from a solid state to a vapor state without entering an intermediate liquid state. A wire mesh 71 prevents non-vaporized decaborane from escaping the crucible 52. Completely vaporized decaborane exits the crucible 52 via feed tube 62 and enters mass flow controller 60, which controls the flow of vapor, and thus meters the amount of vaporized decaborane which is provided to the ionization chamber, as is known in the art. The ionization chamber 58 ionizes the vaporized decaborane that is provided by the mass flow controller 60, also as is known in the art.

[0022] The inventive ion source 50 provides a control mechanism for controlling the operating temperature of the crucible 52, as well as that of the feed tube 62 through which vaporized decaborane passes on its way to the ionization chamber 58. The heating medium 70 is heated within the reservoir 54 by a resistive or similar heating element 80. The temperature control means comprises a temperature controller 56 which obtains as an input temperature feedback from the reservoir 54 via thermocouple 92, and outputs a control signal to heating element 80, as further described below, so that the heating medium 70 in the reservoir is heated to a suitable temperature.

[0023] The heating medium 70 comprises mineral oil or other suitable medium (*e.g.*, water) that provides a high heat capacity. The oil is heated to a temperature within the 20° C to 150° C range by the heating element 80 and circulated by pump 55 around the crucible 52 and the feed tube 62 through sheath 90. The pump 55 is provided with an inlet and an outlet 82 and 84,

respectively, and the reservoir 54 is similarly provided with an inlet 86 and an outlet 88, respectively. The flow pattern of the heating medium about the crucible 52 and the feed tube 62, although shown in a unidirectional clockwise pattern in Figure 2, may be any pattern that provides reasonable circulation of the medium about the crucible 52 and the feed tube 62.

[0024] Referring back to Figure 2, the crucible cavity 66 is pressurized in order to facilitate material transfer of the vaporized (sublimated) decaborane from the crucible 52 to the ionization chamber 58 through the feed tube 62. As the pressure within cavity 66 is raised, the rate of material transfer correspondingly increases. The ionization chamber operates at a near vacuum (about 1 millitorr), and thus, a pressure gradient exists along the entire length of the feed tube 62, from the crucible 52 to the ionization chamber 58. The pressure of the crucible is typically on the order of 1 torr.

[0025] By locating the crucible 52 remotely from the ionization chamber 58, the temperature within crucible cavity 66 is thermally isolated, thereby providing a thermally stable environment unaffected by the temperature in the ionization chamber 58. As such, the temperature of the crucible cavity 66, in which the process of decaborane sublimation occurs, may be controlled independently of the operating temperature of the ionization chamber 58 to a high degree of accuracy (within 1° C). Also, by maintaining a constant temperature of the vaporized decaborane during transport to the ionization chamber 58 via the heated feed tube 62, no condensation or thermal decomposition of the vapor occurs.

[0026] The temperature controller 56 controls the temperature of the crucible 52 and the feed tube 62 by controlling the operation of the heating element 80 for the heating medium reservoir 70. Thermocouple 92 senses the temperature of the reservoir 70 and sends temperature feedback signal 93 to the temperature controller 56. The temperature controller responds to this input feedback signal in a known manner by outputting control signal 94 to the

reservoir heating element 80. In this manner, a uniform temperature is provided for all surfaces to which the solid phase decaborane and vaporized decaborane are exposed, up to the location of the ionization chamber.

[0027] In addition to controlling the temperature of the walls 64 of the crucible 52 and the pressure within the crucible cavity 66, the present invention provides a mechanism for improving the thermal conductivity between the walls 64 and the source material 68. The mechanism comprises a source of gas 96 that is controllably provided to crucible cavity 66 by means of valve 98. In particular, a conduit or tube 100 connects the gas source 96 to the inlet of valve 98, and the outlet of valve 98 is connected to the cavity 66 by tube 102. An exit orifice or injector 104 is provided for the tube 102. In the preferred embodiment, the gas (also referred to herein as a "co-gas") contained within gas source 96 is hydrogen or helium, though other inert gases having suitable coefficients of thermal conductivity are contemplated.

[0028] Gas that enters the cavity 66 via orifice 104 functions to improve the heat transfer characteristic between the crucible walls 64 and the source material 68 being vaporized in the crucible. In this manner, source material is efficiently and completely vaporized, increasing the time during which the crucible can provide vaporized decaborane for a given amount of decaborane source material 68. In addition, the stability of the vaporized output flow is improved.

[0029] The co-gas that is provided to the cavity 66 reduces the variations in temperature of the crucible load that would otherwise result in a decreased vaporized gas flow from the crucible to the ionizer 58 and subsequent reduction of ion source yield. Still further, because a stable supply of vaporized decaborane is supplied to the ionizer 58, the ionizer exhibits improved ion extraction characteristics.

[0030] By controlling the circulation of the heating medium in the system (via pump 55) and the temperature of the heating medium (via heating element 80), the ion source 50 can be controlled to an operating temperature of on the

order of 20° C to 150° C (+/- 1° C). Precise temperature control is more critical at the crucible, as compared to the end of the feed tube nearest the ionization chamber, to control the pressure of the crucible and thus the vapor flow rates out of the crucible. In addition, by controlling the partial pressure of the decaborane within the crucible cavity, the uniformity of the vapor flow out of the crucible is improved.

[0031] Figure 3 shows the manner in which the addition of the co-gas (in this case helium at a rate of 0.5 sccm) in the crucible cavity stabilizes the partial pressure of the decaborane over the entire course of operation of the vaporizer. In Figure 3, the decaborane vapor partial pressure in the crucible cavity 66 is shown both when using the helium co-gas, and without. As shown in Figure 3, when the co-gas is not utilized, the decaborane partial pressure initially spikes and then quite rapidly decreases. However, when the co-gas is used, the decaborane partial pressure remains relatively stable throughout most of the three hour period shown. As a result, the vaporized decaborane output of the crucible is correspondingly stabilized.

[0032] Using the ion source 50 of Figure 2 in an ion implanter, an entire molecule (ten boron atoms) is implanted into the workpiece. The molecule breaks up at the workpiece surface such that the energy of each boron atom is roughly one-tenth the energy of the ten-boron cluster (in the case of $B_{10}H_{14}$). Thus, the beam can be transported at ten times the desired boron implantation energy, enabling very shallow implants without significant beam transmission losses.

[0033] In addition, at a given beam current, each unit of current delivers ten times the dose to the workpiece. Still further, because the charge per unit dose is one-tenth that of a monatomic beam implant, workpiece charging problems are much less severe for a given dose rate. Finally, because of the presence of the co-gas in the vaporizer cavity, the thermal conductivity of the source material with the cavity walls is improved, resulting in a uniform and stable

vapor flow output by the vaporizer.

[0034] Accordingly, a preferred embodiment of an improved ion source for an ion implanter has been described. With the foregoing description in mind, however, it is understood that this description is made only by way of example, that the invention is not limited to the particular embodiments described herein, and that various rearrangements, modifications, and substitutions may be implemented with respect to the foregoing description without departing from the scope of the invention as by the following claims and their equivalents.

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